NASA-CR-204393

NDB IN-61-CR

NAG 5-2167

Robust EZW Image Coding For Noisy Channels *

Hong Man [1], Faouzi Kossentini [2], and Mark J. T. Smith [1]

[1]School of Electrical and Computer Engineering,
Georgia Institute of Technology,
Atlanta, GA 30332-0250, USA

[2]Department of Electrical Engineering,
University of British Columbia,
Vancouver BC V6T 1Z4, Canada

October 22, 1996

Abstract

We present a new embedded zerotree wavelet image coding algorithm, that is based on the algorithms developed by Shapiro and Said et. al. Our algorithm features a relatively simple coding structure, and provides a better framework for balancing between high compression performance and robustness to channel errors. The fundamental approach is to explicitly classify the encoder's output bit sequence into subsequences, which are then protected differently according to their importance and robustness. Experimental results indicate that, for noisy channels, the proposed algorithm is slightly more resilient to channel errors than more complex and sophisticated source-channel coding algorithms. More important is that our algorithm is substantially more robust with respect to varying channel error conditions. This provides much needed reliability in low-bandwidth wireless applications.

*This work was supported by the Natural Sciences and Engineering Research Council of Canada under grant # OGP-0187668 and NASA.

1 Introduction

Embedded Zerotree Wavelet (EZW) image coding algorithms are relatively new, although they have recently been extensively studied in the context of still image and video compression. Variations of the original EZW algorithm, introduced by Shapiro in [1], have been developed that achieve very good complexity-performance tradeoffs. Most notable is the extended EZW (E-EZW) algorithm developed by Said and Pearlman in [2]. The E-EZW algorithm not only outperforms other EZW ones but also provides an alternative explanation and implementation of the EZW principles.

EZW image coding consists generally of a pyramid wavelet subband decomposition of the original image and embedded bit plane encoding of wavelet coefficients (or pixels) populating a tree structure. The tree structure can be defined as a group of pixels crossing different scales along a certain direction. A tree node, combined with all its descendants, forms a spatial orientation tree. The actual values of the pixels are transmitted progressively by bit plane coding, which is usually performed in two passes: a dominant pass where significant pixels are identified and a subordinate pass where such pixels are refined. Most of the efficiency of EZW results from spatially ordering the pixels by their magnitudes and effectively coding their coordinates.

The main difference between the various EZW approaches lies in the way the significance map is coded during the dominant pass. In [1], all necessary pixels are scanned according to a certain order and are then classified into four symbols, which are coded using arithmetic coding. A different approach is described in [3], where a rate-distortion optimized extension of [1] is developed. Other significance map coding techniques have been recently introduced, but the E-EZW technique [2] stands as the simplest and most efficient. The E-EZW algorithm employs a set of pre-determined variable length codes (VLCs) and a set partitioning rule to code the significance map very efficiently, yielding the best known complexity-performance tradeoffs.

While it achieves very high coding efficiency, the E-EZW algorithm is also extremely sensitive to channel noise. This is due mainly to the built-in tree structure of the general zero-tree approach and the implicit dependence of the significance map coding strategy. A single bit error can easily cause loss of synchronization between the encoder and decoder execution paths, which would lead to an uncontrolled degradation in reproduction quality. Channel codes such as the powerful rate compatible punctured convolutional (RCPC) codes [4] can be used to significantly increase channel error resilience for a specific channel bit error rate (BER), but higher resilience can still be achieved by decreasing the sensitivity of the source coder (compression) output to channel errors. Less sensitive source coders can also substantially increase channel error robustness over a wide range of BERs.

In this letter, we simplify the E-EZW coding structure and provide more channel error resilience and robustness, while still achieving high compression performance in a noiseless environment. The fundamental approach is to remove unnecessary dependent coding and classify the coding bit sequence into subsequences that can be protected differently using RCPC codes according to their importance and sensitivity. Next, we briefly describe the proposed algorithm. This is followed by a discussion of some experimental results.

2 Proposed E-EZW Algorithm

Like the E-EZW algorithm described in detail in [2], the proposed E-EZW algorithm encodes the subband pixels by performing a sequence of dominant and subordinate passes. The dominant pass consists of two tests: the node test (NT) and the descendant test (DT). The NT produces VLCs representing individual pixels, while the DT produces VLCs describing the significance map. In each NT of the original E-EZW algorithm, pixels in the list of insignificant pixels (LIP) are tested and coded as follows: If the pixel is insignificant with respect to a threshold, **0** is emitted, and the node will be tested again during the next NT. Otherwise, either **10** (positive) or **11** (negative) is emitted, and the node will be removed from the LIP and added to the list of significant pixels (LSP).

The NT of the proposed E-EZW is re-structured so that it produces fixed length (FL) codes. Instead of generating the bit **0** for an insignificant pixel, our NT generates the bits **00** for a positive insignificant pixel and the bits **01** for a negative insignificant pixel. Moreover, this pixel will not be tested again as it will henceforth be considered significant. This re-structuring simplifies the entire coding structure, since each pixel in the LIP is tested exactly once by the NT and can only be refined in subsequent passes.

The DT results are variable length (VL) coded as described in [2]. More specifically, one bit (**0**) is emitted if all descendants of the subject node are insignificant while $2-3$ bits are emitted otherwise. Most images have a substantial portion of their energy concentrated in the lowest frequency band. Thus, if a spatial orientation tree contains significant pixels, it is more likely that such pixels will be found at the root. As the above VL coding method spares one bit to convey this likely event, only a few bits are usually needed to code the DT results.

After completing the node and descendant tests, we perform a subordinate pass, where each significant pixel is refined. The refinement output bits, like the NT results, are FL coded.

Clearly, our algorithm produces three different bit subsequences: (1) the NT subsequence representing the FL coded NT output, (2) the DT subsequence representing the VL coded significance map, and (3) the refinement subsequence. These subsequences are RCPC protected differently depending on their structures.

3 Experimental Results

The popular 512×512 Y-component LENA image is used for testing. The input image is first decomposed into a five-level pyramid using the 9/7-tap filter bank described in [2]. The algorithm discussed above is then applied producing three bit subsequences. Arithmetic coding is not applied to the NT/refinement subsequences because it would destroy the FL coding structure built by our algorithm. It is also not applied to the DT subsequence because the associated compression performance gain does not usually justify the additional complexity demands. To simulate the performance of our algorithm over a noisy channel, we employ a binary symmetric channel (BSC) model and the RCPC protection codes shown in Table I of [4]. The Viterbi algorithm is used for hard-decision decoding of the BSC output.

For a noiseless channel, our algorithm achieves approximately 0.25 dB and 1.00 dB less in PSNR relative to E-EZW-I (E-EZW without arithmetic coding) and E-EZW-II (E-EZW with arithmetic coding), respectively. For a noisy channel, our algorithm is slightly more resilient (even using RCPC protection) and is much more robust. For example, Figure 1 shows the performance of three source-channel codecs designed for 0.25 bits per pixel (bpp) over a 10^{-3} BER noisy BSC, where the simulation is repeated 60 times. One of the codecs is E-EZW-II/RCPC, which significantly outperforms a similarly RCPC protected E-EZW-I. Both codecs I & II are based on the proposed algorithm. Codec I and E-EZW-II/RCPC use the same overall RCPC protection rate of 8 : 13 (i.e., approximately 40% are source coding bits and 60% are channel coding bits). Codec II spends less bits to protect the NT/DT subsequences, increasing the portion of source coding bits to roughly 80%. The refinement subsequence is not protected in both codecs. One can see that there is a tradeoff between source coding and channel protection bits, that directly influence resilience for a particular BER (10^{-3}) and robustness over many BERs. Codec I is less resilient than E-EZW-II/RCPC for a 10^{-3} BER, but is substantially more robust for higher BERs. Since codec I is over protected, it is suited for applications where the channel BER characteristics are time-varying. Codec II is both slightly more resilient and significantly more robust than E-EZW-II/RCPC. Codec II appears to achieve a better balance between resilience and robustness.

When compared to some of the best reported source-channel codecs [5, 6], our codecs achieve significantly better rate-distortion performance, although they are optimized for robustness. For example, Table 1 shows the PSNRs of codec II, the S/C-SUB(D) of [5], and the more recent A-RQ of [6]. The S/C-SUB(D) is based on pyramid subband coding, with the lowest frequency subband coded by 2-D DCT, the rest of the subbands coded by PCM, and the source coder's output protected by RCPC codes. The A-RQ is based on a subband decomposition followed by allpass filtering and channel optimized scalar quantization. One can see that, although our algorithm is simpler, almost 1 dB and 2 dB improvements are obtained for overall bit rates of 0.25 and 0.50 bpp, respectively.

References

[1] J. M. Shapiro, "Embedded image coding using zerotrees of wavelet coefficients," *Special Issue on Wavelets and Signal Processing*, vol. 41, pp. 3445–3462, Dec. 1993.

[2] A. Said and W. A. Pearlman, "A new fast and efficient image codec based on set partitioning in hierarchical trees," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 6, pp. 243–250, June 1996.

[3] Z. Xiong, C. Herley, K. Ramchandran, and M. T. Orchard, "Space-frequency quantization for a space-varying wavelet packet coder," in *International Conference on Image Processing*, (Washington, DC), pp. 614–617, Oct. 1995.

[4] J. Hagenauer, "Rate-compatible punctured convolutional codes and their applications," *IEEE Trans. on Communications*, vol. 36, pp. 389–400, Apr. 1988.

[5] N. Tanabe and N. Farvardin, "Subband image coding using entropy-coded quantization over noisy channels," *IEEE Journal on Selected Areas in Communications*, vol. 10, pp. 926–943, June 1992.

[6] Q. Chen and T. R. Fischer, "Robust quantization for image coding and noisy digital transmission," in *IEEE Data Compression Conference*, (Snowbird, UT, USA), pp. 3–12, Mar. 1996.

List of Figures

1 Source-channel codecs Designed for 0.25 bpp over 10^{-3} BER Noisy BSC. 9

List of Tables

1 PSNR (in dB) of our codec II, S/C-SUB(D), and A-RQ for the 512×512 LENA image at 10^{-2} and 10^{-3} BERs and overall bit rates of 0.25 and 0.25 bpp. 9

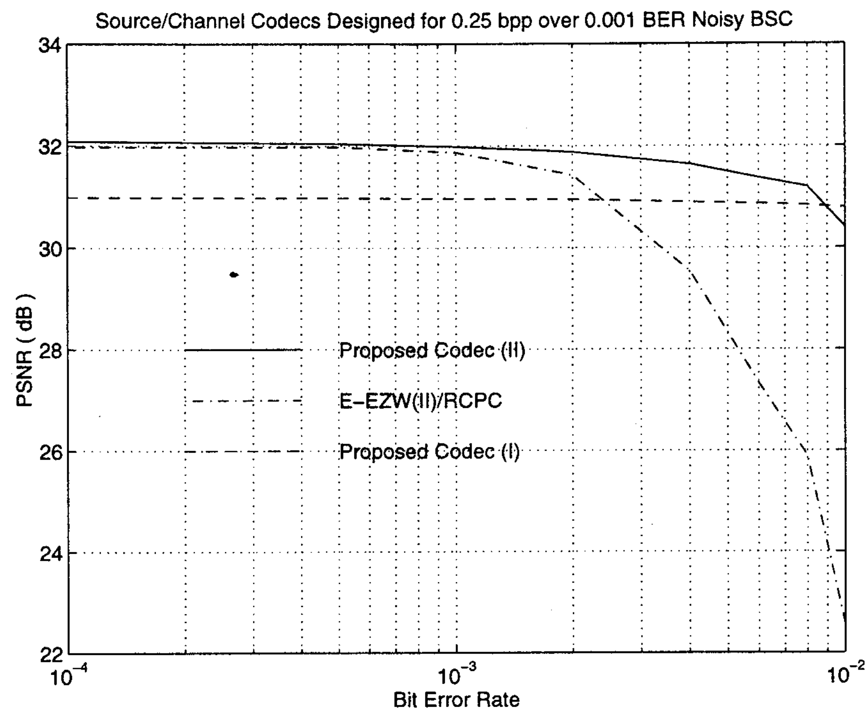

Figure 1: Source-channel codecs Designed for 0.25 bpp over 10^{-3} BER Noisy BSC.

	0.25 bpp		0.50 bpp	
	$BER = 10^{-2}$	$BER = 10^{-3}$	$BER = 10^{-2}$	$BER = 10^{-3}$
Our codec II	30.79	31.98	33.62	35.08
S/C-SUB(D)	29.96	30.94	32.38	33.90
A-RQ	29.24	30.34	31.42	33.00

Table 1: PSNR (in dB) of our codec II, S/C-SUB(D), and A-RQ for the 512×512 LENA image at 10^{-2} and 10^{-3} BERs and overall bit rates of 0.25 and 0.25 bpp.